Ducted Systems- Technical Overview

Constant Volume, Single Zone VAV, Change over Bypass and Variable Air Volume Systems

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This technical bulletin document covers several type of air delivery systems. The key focus of this bulletin is to provide basic education on the most commonly used systems and also unique features such as IntelliSpeed™ and CRSZ Control (Continuous Reset Single Zoning).

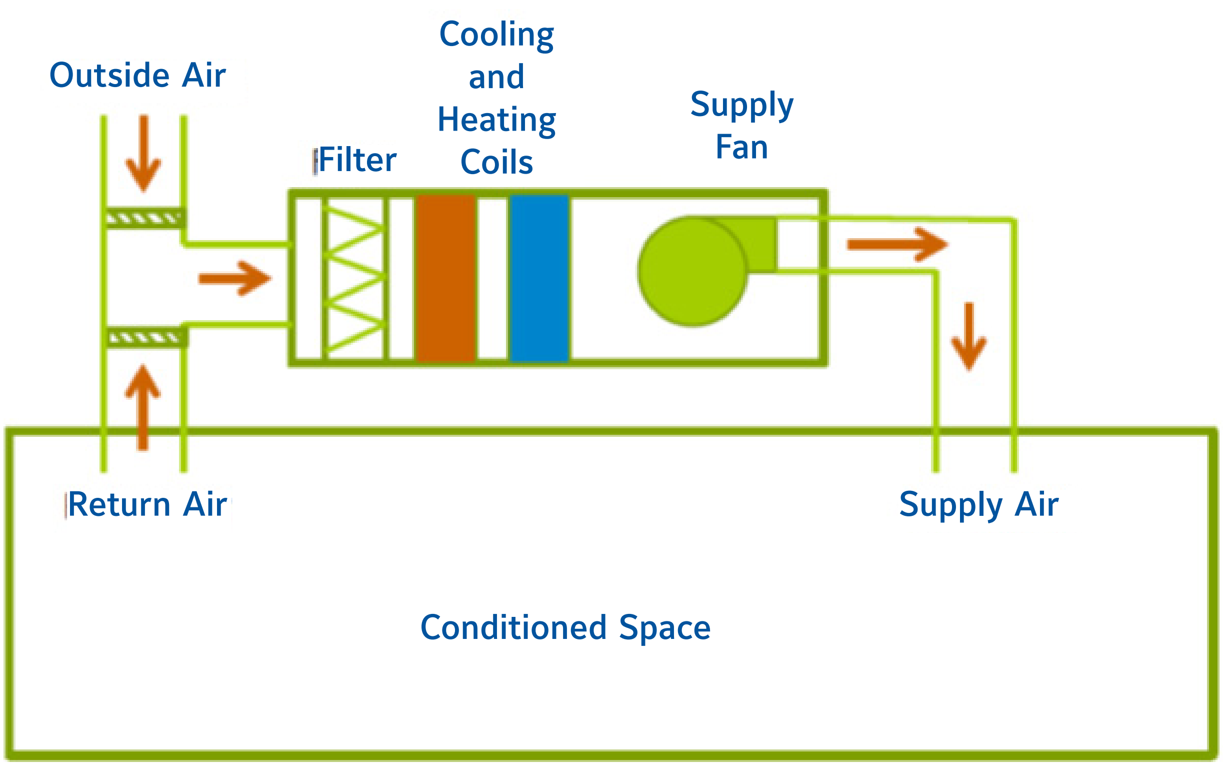
Constant Air Volume (CAV)

is a type of heating, ventilating, and air-conditioning (HVAC) system. In a simple CAV system, the supply air flow rate is constant, but the supply air temperature is varied to meet the thermal loads of a space.

The simplified drawing below provides a depiction of a typical constant volume air flow application of a residential or commercial DX application. The duct design is relatively simple and does not include any manual or motorized dampers within the supply or return portions of the ductwork. The airflow amount from the supply fan remains constant as well as the air volume supplied throughout the duct system. The control and staging of the constant volume HVAC equipment is usually handled through a wall thermostat or 24 volt signals to the HVAC unit control. In a CAV system the fan delivers constant air volume while compressor on and off staging provides varying levels of cooling to maintain Space/Zone Temperature (ST).

Constant volume systems provide fan operation during occupied heating/cooling schedules or the supply fan may cycle on and off based off of cooling or heating demand for the space. The single advantage of CV system is that the equipment is not equipped with a VFD and is usually at a lower cost point than single zone VAV or true VAV systems. A disadvantage of constant volume systems is that the system lacks precise control of space temperature resulting in moderate temperature and humidity swings. Energy use with CAV systems is usually greater than variable air volume systems.

Figure 1. Constant Volume System (CAV)

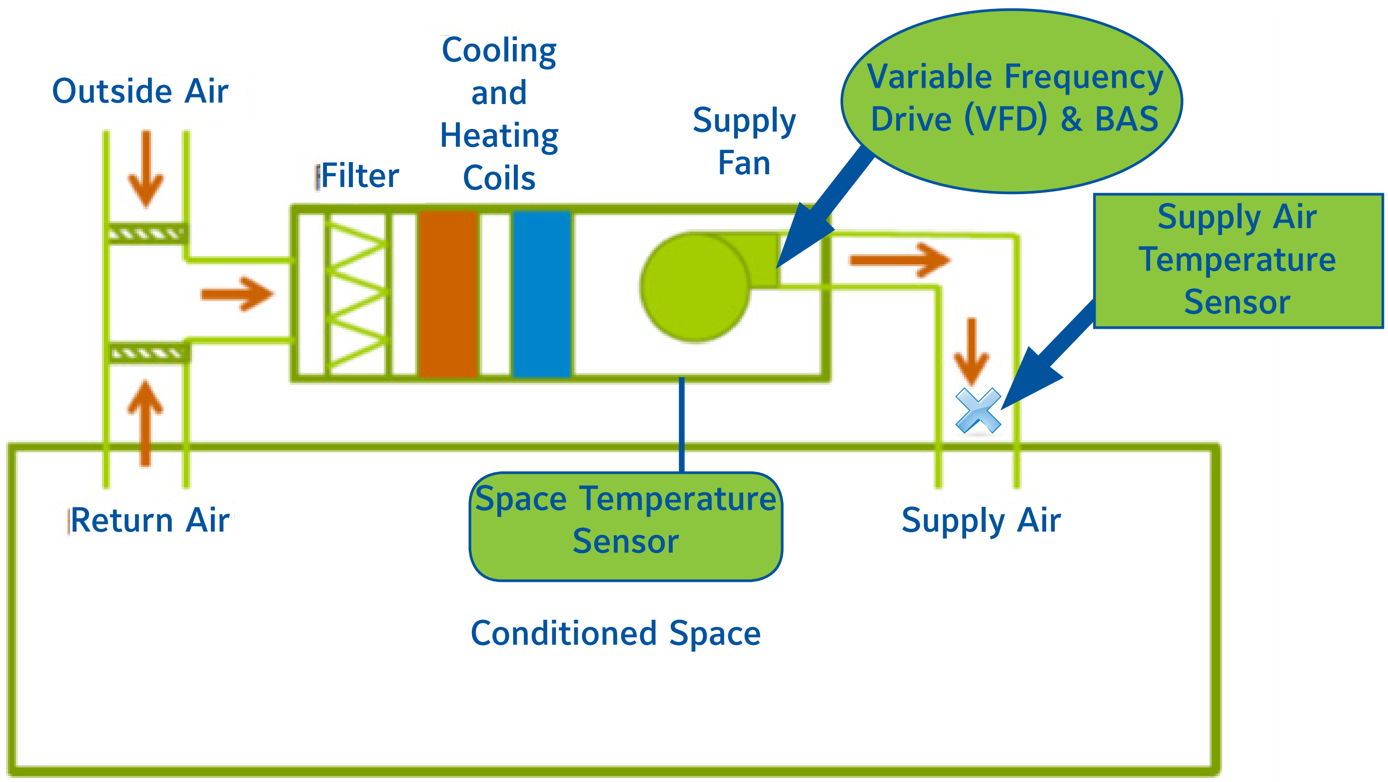


Single Zone Variable Air Volume (SZVAV)

In a single zone VAV unit, a variable speed fan controls the amount of airflow provided to the space by modulating the fan motor speed based on the difference between the actual space temperature(ST) and the supply air temperature (SAT).

The unit uses the supply air temperature leaving the unit to determine how much cooling or heating will be required to maintain the supply air temperature setpoint. The supply air temperature is maintained by increasing or decreasing air flow and staging compressors off or on.

Figure 2. Single Zone Variable Air Volume System (SZVAV)



CRSZ Control (Continuous Reset Single Zone Control)

Unlike typical Single Zone VAV system operation Ducted System's CRSZ option provides precise control of space comfort while maximizing energy savings. Comfort and energy savings are accomplished by the equipment's Smart Equipment controller, the controller utilizes multiple inputs such as Operational Space Temperature (OprST), Supply Air Temperature (SAT) and Evaporator Coil sensors (EC) to control fan speed and compressor staging to provide optimal comfort yet using as little energy as possible.

Key Advantages of CRSZ Control:

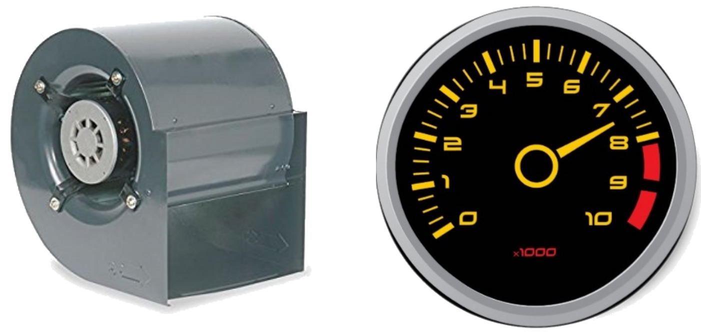
- Seeks to balance compressor staging and fan speed to deliver stable zone temperature and humidity control
- Operates with minimum fan speed needed to maximize energy saving and comfort
- Specifiable feature – Ideal for many applications
- Based on % Demand for cooling – algorithm developed that focuses to maintain space/zone temperature with changing load characteristics.

The continuous reset single zone (CRSZ) operation can be understood by a simple analogy.

CRSZ control operation could be considered similar to that of an automobile, with compressor stages as the gears of the transmission, supply fan speed as the engines RPM and Supply Air Temperature (SAT) being represented as hills, valleys and headwinds seen on the open road.

Figure 3. CRSZ Control Analogy

Compressors are like gears



Fan Speed is like RPM

SAT is like Speed Setpoint

Space Temperature acts as hills and valleys, headwind, etc.

How CRSZ control would act similar to the operation of driving an automobile? It would look something like this...

Compressor staging and airflow adjust to satisfy the Supply Air Temperature just as an automobile will change gears and engine RPM to maintain the speed of the automobile – i.e., 65 MPH, or in the case of SAT, 55-65F°.
So as we consider the space temperature as hills, valleys and head-winds seen while driving, road conditions will change constantly requiring the automobile to change gears up or down and increase or lower engine RPM to maintain a constant speed (MPH).

In the CRSZ mode the HVAC unit will adjust to changes seen in the space temperature due to increased or decreased cooling loads. Compressors will be staged on or off, fan speed will increase or decrease in order to maintain a consistent space temperature.

So consider how CRSZ or an automobile will react to conditional changes. If an automobile approaches a steep hill it will attempt to maintain 65 MPH so the transmission will shift to a lower gear, the throttle will increase resulting in higher engine RPM that creates more engine horsepower to avoid dropping below 65 MPH. CRSZ control would react similarly if the space temperature increases due to additional load. An increase in space temperature will result in the supply air temperature resetting to a lower point in order to drive an increase in fan speed and activate additional compressor staging. The end result is additional cooling to maintain space/zone setpoint temperature.

So consider how CRSZ or an automobile will react to conditional changes. If an automobile approaches the downhill side of a valley and is attempting to maintain 65 MPH the transmission will shift to a higher gear, the throttle will decrease resulting in a lower engine RPM thus decreasing engine horsepower in order to not exceed 65 MPH. CRSZ control would react similarly if the space temperature decreases due to a reduction in cooling load. A decrease in space temperature will result in the supply air temperature resetting to a higher point in order to drive a decrease in fan speed and a reduction in compressor staging. The end result is a reduction in cooling to maintain space/zone setpoint temperature.

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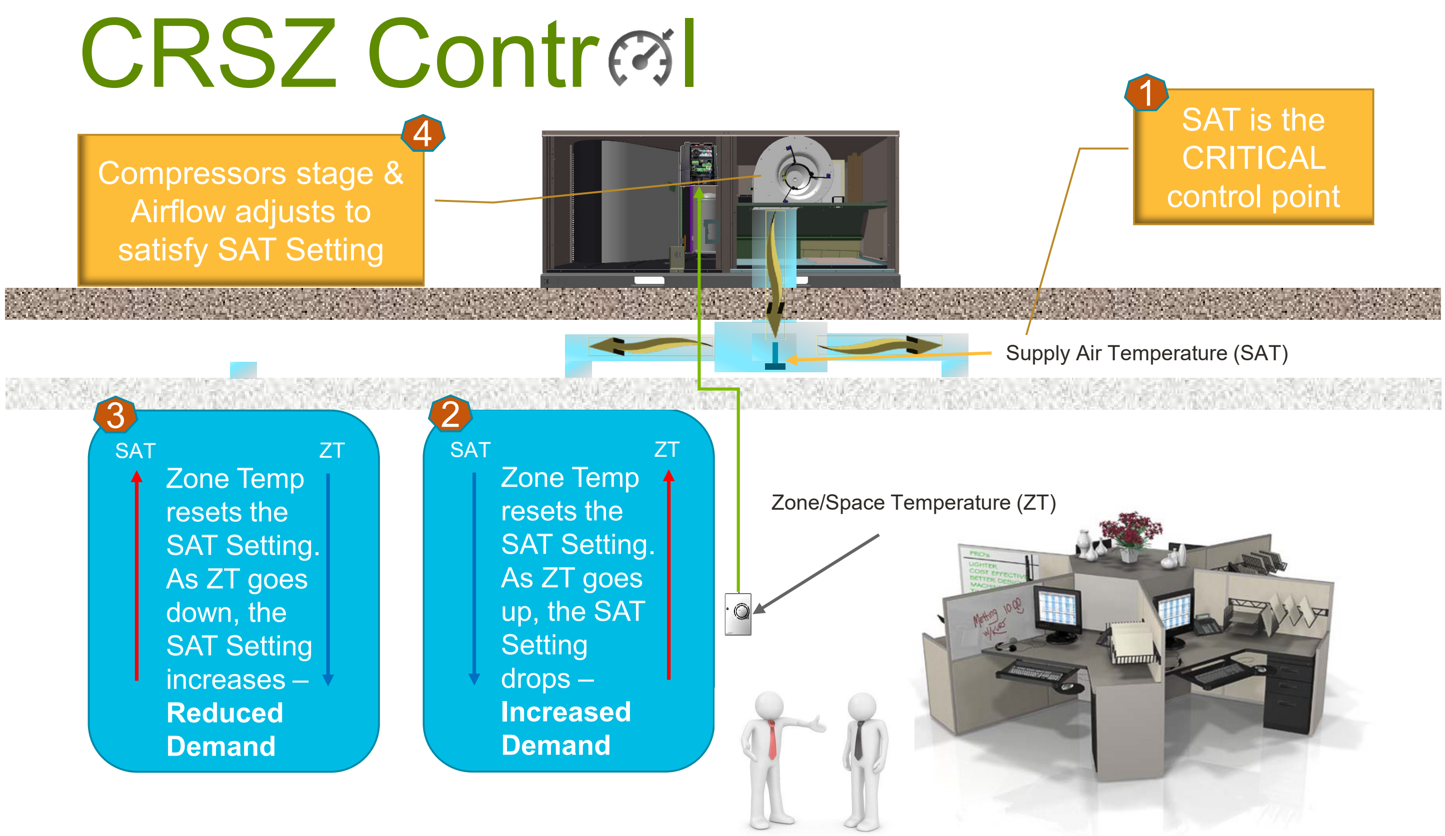
Figure 4. CRSZ Control Simplified



Ducted Systems Continuous Reset Single Zone Control (CRSZ) Sequence of Operation

The following information can be found in the Smart Equipment Control's sequence of operation guide LIT-12011950-D-0119. This section details the single zone VAV (SZ VAV) setpoints and related data, inputs, outputs, and operation.

Setpoints and related data

The setpoints and related data include the following items:

- VAV cooling SAT upper setpoint (**SATUp-Sp**, AV 29604)
- VAV cooling SAT lower setpoint (**SATLo-Sp**, AV 29605)
- SZ VAV operating cooling setpoint (**OprSZVAVClg-Sp,** AV 29927)
- Fan control type (**FanCtl-Type**, MV 29555) - Variable Speed
- SZ VAV enabled (**SZVAVEn**, MV29908) - Yes
- SZ VAV occupied cooling setpoint (**SZVAVClgOcc-Sp,** AV 29925)
- SZ VAV unoccupied cooling setpoint (**SZVAVClgOcc-Sp**, AV 29926)
- SZ VAV minimum fan speed (**SZVAVMinFanSpd,** AV 29913)
- SZ VAV cooling load (**SZVAVClgLd**, AV 29935)

Inputs

The inputs include the following items:

- Operational space temperature (**OprST**, AV 29522)
- Supply air temperature **(SAT,** AV 29564)
- Evaporator coil sensors (EC1, EC2, EC3, EC4, AV 29663 through AV 29666)

Outputs

The outputs include the following items:

- Fan % command **(FanVFD**, AV 29551)
- Compressor stage commands (C1, C2, C3, C4, MV 29611 through MV 29614)

Operation

Note:

To operate in SZ VAV mode the control must be in an occupied mode. The Smart Equipment Control must be changed during field installation to reflect a fan control type of variable speed and the SZ VAV mode will need to be enabled.

- Without a demand for cooling and the staged cooling command is 0%, the fan % command is at the SZ VAV minimum fan speed. The SZ VAV operating cooling setpoint is equal to the VAV cooling supply air temperature upper setpoint.
- If the operational space temperature is above the SZ VAV occupied cooling setpoint by more than half of the cooling manual tuning amount, the staged cooling command increases.
- If the operational space temperature is within half of the cooling manual tuning amount of the SZ VAV operating cooling setpoint the staged cooling command does not change.
- If the operational space temperature is less than half of the cooling manual tuning amount below the SZ VAV operating cooling setpoint, the staged cooling command decreases.
- Compressor outputs energize and de-energize based on the staged cooling command according to the following table.

No. Stages	PID Percent Command							
	1st Stage		2nd Stage		3rd Stage		4th Stage	
	On	Off	On	Off	On	Off	On	Off
1	100%	0%						
2	50%	0%	100%	50%				
3	33%	0%	66%	33%	100%	66%		
4	25%	0%	50%	25%	75%	50%	100%	75%

As the staged cooling command increases the SZ VAV operating cooling setpoint decreases proportionately between the VAV cooling SAT upper setpoint and the VAV cooling SAT lower setpoint. As the staged cooling command decreases the SZ VAV operating cooling setpoint increases proportionately between the VAV cooling SAT upper setpoint and the VAV cooling SAT lower setpoint.

- If the staged cooling command is >0%, FanVFD output modulates to control the SAT to the SZ VAV operating cooling setpoint +/- 0.6°F.
- If the SAT drops below the SZ VAV operating cooling setpoint by more than 0.60°F, FanVFD increases to raise the SAT within SZ VAV operating cooling setpoint within 0.60°F.
- If the SAT rises above SZ VAV operating cooling setpoint by more than 0.60°F, FanVFD decreases to lower the SAT to within 0.6°F of the SZ VAV operating cooling setpoint.

If any of the evaporator coil sensor values (EC1, EC2, EC3, EC4) go below 42°F, FanVFD increases proportionally to the number of degrees below 42°F according to the following table.

EC Temp (°F)	Additional Fan Speed
42	0
41	6
40	13
39	19
38	25
37	31
36	38
35	44
34	50
33	56
32	63
31	69
31	75
30	81
29	88
27	94
26	100

Note:

The Fan VFD cannot drop below 20Hz or 33% at any time.

Note:

In compliance with ASHRAE 90.1-2010 Section 6.4.3.10, the fan % command (FanVFD) cannot operate above 67% when the staged cooling command (StgClgCmd) is at or below 50%.

During free cooling operation, the fan cannot operate above 67% if the SZ VAV cooling load is at or below 50%.

Economizer free cooling operation

If free cooling is available and the operating space temperature is greater than the SZ VAV occupied cooling setpoint, FanVFD output changes proportionately between the SZ VAV minimum fan speed and 67% or 100% (maximum fan speed, dependent on the SZ VAV cooling load).

Note:

The operational space temperature and the SZ VAV occupied cooling setpoint drive the SZ VAV cooling load when the unit is free cooling. This process controls the FanVFD speed, as the demand increases, the fan increases CFM to match.

With free cooling available and the SZ VAV cooling load above zero, the SZ VAV operating cooling setpoint resets proportionally between the VAV cooling SAT upper and lower sepoints. The economizer analog output (ECON) modulates to control supply air temperature to the SZ VAV operating cooling setpoint +/-1.8°F. If ECON reaches 100% and remains there for 5 consecutive minutes, the control moves to Econ+Mech mode and the staged cooling command begins to accumulate at a rate determined by how much warmer the supply air temperature is from the SZ VAV operating cooling setpoint (starting above 1.8°F setpoint).

When the SZ VAV cooling load reaches 0%, the control ceases free cooling operations and moves to a satisfied condition where it runs the fan at the SZ VAV minimum fan speed.

IntelliSpeed Multi-Speed Fan Control (Discrete Fan)

Recent code changes have demanded the need for two or more fan speeds to be available on HVAC products with cooling capacities of 65,000 Btu/h or greater. Under recent ASHRAE 90.1-2013 and IECC 2015 or newer the following is required in states that have adopted either of the codes mentioned above:

- "All air-conditioning equipment and air handling units with direct expansion cooling capacity at ARI conditions greater than or equal to 65,000 Btu/h that serve single zones shall have their supply fan controlled by two-speed motors or variable-speed drives. At cooling demands less than or equal to 50% the supply fan controls shall be able to reduce the airflow to no greater than the larger of the following:
    1. Two-Thirds of the full fan speed or
    2. The volume of outdoor air required to meet the ventilation requirements of Standard 62.1.

The IntelliSpeed option is available on select Ducted Systems products 6-40 tons and split air handlers 7.5-25 tons. Typical fan operation is as follows:

- Airflow is adjusted automatically based on predetermined fan speed set at the factory. Fan speed is controlled by the VFD voltage, frequency output to the motor.
- Fan speed is controlled by various inputs. A "G" signal or fan only will run the fan at 50% of total airflow.
- A first stage cooling signal (Y1) will drive the fan at approximately 67% or two-thirds of total airflow. The VFD drive will be pre-programmed to run at X frequency based on the on G, Y1, Y2 inputs. A second stage cooling signal (Y2) will drive the fan to approximately 100% or full airflow. <u>This applies to two stage cooling units only.</u>

- Equipment equipped with four stages of cooling will operate in the following manner: A "G" signal or fan only will run the fan at 50% of total airflow. A first stage cooling signal (Y1) will drive the fan at approximately 67% or two thirds of total airflow. A second stage cooling signal (Y2) will drive the fan at 75% or three quarters of total airflow. A third stage cooling signal (Y3) will drive the fan at approximately 85% or seven eights of total airflow. A fourth stage cooling signal (Y4) will drive the fan at 100% or total airflow. <u>This applies to four stage cooling units only.</u>

There are several advantages of utilizing a VFD drive to provide multiple fan stages.

Key Advantages of IntelliSpeed Fan Control:

- Energy savings- Using VFDs to drive fans results in reduced fan energy consumption up to 87% when operating at 40% system airflow. A substantial energy savings over a single speed fan.
- Improved humidity control and space temperature. Reduced airflow and compressor staging will improve space temperature and humidity levels and save energy over that of a conventional single speed fan system.
- Noise or sound level reduction over single speed fan systems. A multi-stage cooling and fan system will reduce noise levels in the indoor space when running at less than 100% full capacity.

Change Over Bypass Air Volume System (COBP)

Change over bypass duct systems are designed to provide cooling to individual zones while maintaining a constant supply air temperature. Each zone's airflow is regulated through zone dampers that adjust airflow volumes based on the zones need for cooling or heating.

A Change Over Bypass system utilizes constant volume equipment that runs the supply fan at a fixed RPM and delivers constant air volume at all times. The COBP systems zone dampers will open and close based on heating/cooling demand in individual zones. The duct pressure will increase when zone dampers close, duct pressure will decrease as zone dampers open. As in any HVAC air moving system fluctuating duct pressure is not desired and will cause issues with maintaining consistent zone temperatures and also erratic airflow noise issues.

So how do you overcome fluctuating duct pressures when dealing with zone dampers? The best option is to modulate the supply air volume by using a Variable Frequency Drive (VFD) or installing a bypass damper. In the case of a COBP system a bypass damper is installed between the supply air and return air portions of the ductwork to help maintain constant duct pressure. How does this work?

- Change over bypass systems will modulate dampers in order to deliver proper airflow to zones or building spaces that require conditioning. The HVAV equipment will deliver a constant SAT and will stage compressors as needed to maintain a constant SAT temperature. Heating with COBP systems usually operates at full airflow and does not modulate zone or bypass dampers (zone dampers are forced full open).
- On a COBP system when zones require cooling the zone dampers will open increasing the airflow to the zone. When the zone dampers open the duct pressure will drop, to overcome this the bypass damper will close helping maintain duct pressure.
- On a COPB system when zones require less cooling the zone dampers will close reducing the airflow to the zone. When the zone dampers close the duct pressure will increase, to overcome this the bypass damper will open helping maintain duct pressure.
- The zones themselves will have individual zone/space temperature sensors that will drive the zone dampers open or closed based on the cooling demand of the space.

There are several advantages of utilizing a Change Over Bypass System.

Key Advantages of a Change Over Bypass Systems (COBP):

- Zone/Space temperatures tend to maintain a more consistent temperature and humidity levels than conventional constant volume systems.
- Saves energy by only cooling zones as required, thus resulting in lower energy bills and more comfortable occupants of the space.
- Eliminates cool and hot zones that are commonly seen with constant volume systems.
- Lower first cost over conventional variable air volumes systems that utilize variable frequency drives.

Figure 5. Change Over Bypass System Diagram

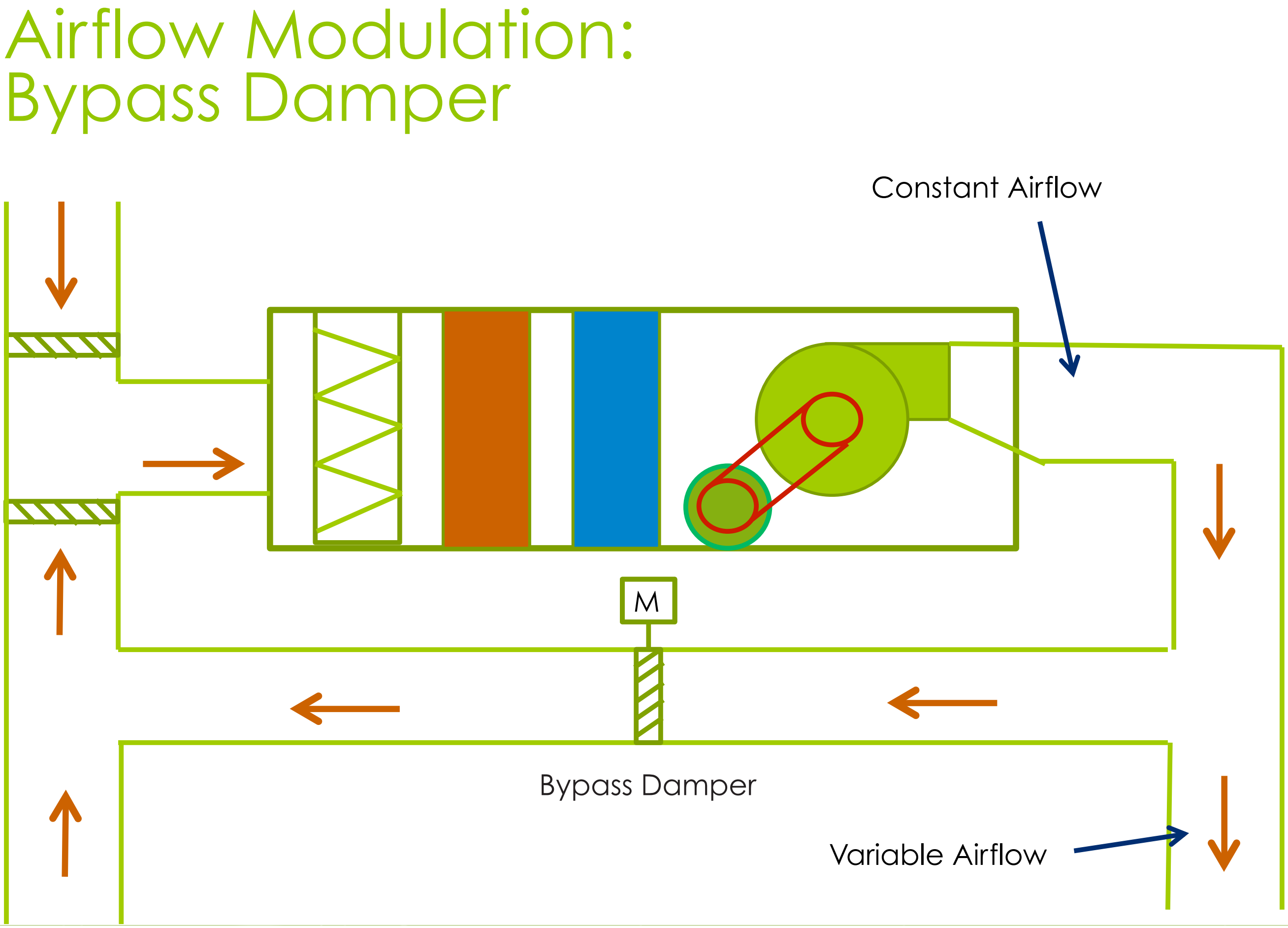
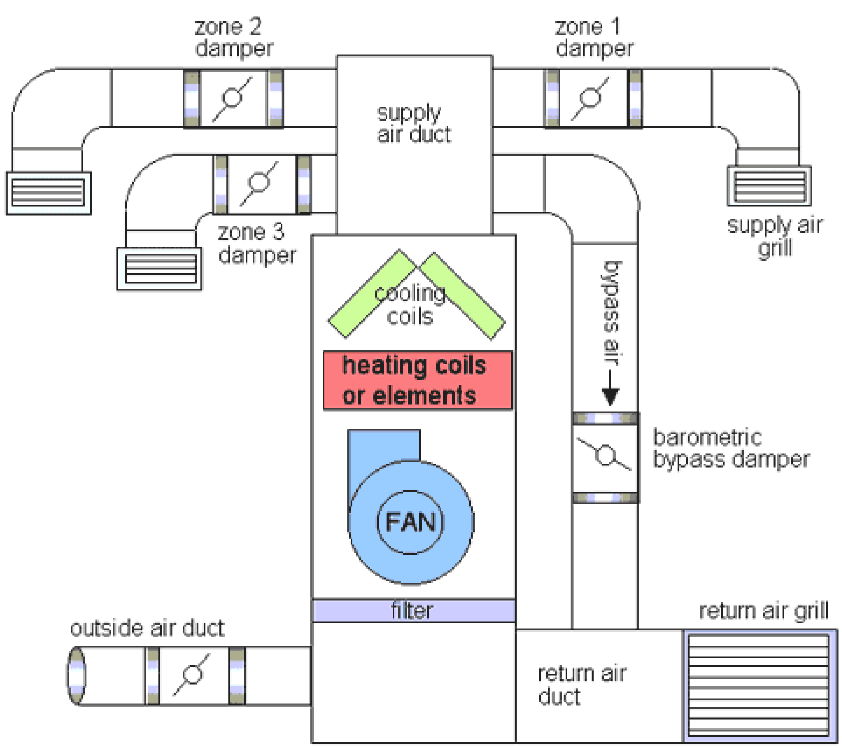


Figure 6. Change Over Bypass System Diagram (Complete Damper System)



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Variable Air Volume System (VAV)

Variable Air Volume (VAV) is a type of heating, ventilating, and/or air-conditioning (HVAC) system. Unlike constant air volume (CAV) systems, which supply a constant airflow at a slightly variable temperature, VAV systems vary the airflow to maintain a constant supply air temperature and duct pressure.

So how do you overcome fluctuating duct pressures when dealing with zone dampers? The best option is to modulate the supply air volume by using a Variable Frequency Drive (VFD) or installing a bypass damper. In the case of a VAV system zone dampers are installed in each damper and the units supply fan is equipped with a variable frequency drive to help maintain constant duct pressure. How does this work?

- A VAV system will modulate both zone damper position and airflow in order to maintain setpoint temperature of spaces that require conditioning. The HVAV equipment will deliver a constant SAT by having the VFD vary fan speed and stage compressors as needed. Heating with VAV systems usually operates at full airflow and does not modulate zone dampers (zone dampers are forced full open).
- On a VAV system when zones require cooling the zone dampers will open increasing the airflow to the zone. When the zone dampers open the duct pressure will drop, to overcome this the VFD will increase the supply fan speed helping maintain duct pressure.
- On a VAV system when zones require less cooling the zone dampers will close reducing the airflow to the zone. When the zone dampers close the duct pressure will increase, to overcome this the VFD will decrease the supply fan speed helping maintain duct pressure.
- The zones themselves will have individual zone/space temperature sensors that will drive the zone dampers open or closed based on the cooling demand of the space.

There are several advantages of utilizing a VFD drive to provide variable fan speeds.

Key Advantages of a Variable Air Volume System (VAV):

- Energy savings- Using VFDs to drive fans results in a potential reduced energy consumption up to 87% when operating at 40% system airflow. A substantial energy savings over a single speed fan.
- Improved humidity control and space temperature. Reduced airflow and compressor staging will improve space temperature and humidity levels and save energy over that of a conventional single speed fan system.
- Noise or sound level reduction of single fan systems. A multi-stage cooling and variable fan system will reduce noise levels for both the indoor and outdoor spaces when running at staging less than 100% full capacity.
- Zone/Space temperatures tend to maintain a more consistent temperature and humidity levels than conventional constant volume systems.
- Saves energy by only cooling zones as required, thus resulting in lower energy bills and more comfortable occupants of the space.
- Eliminates cool and hot zones that are commonly seen with constant volume systems.

Figure 7. Variable Air Volume System Diagram

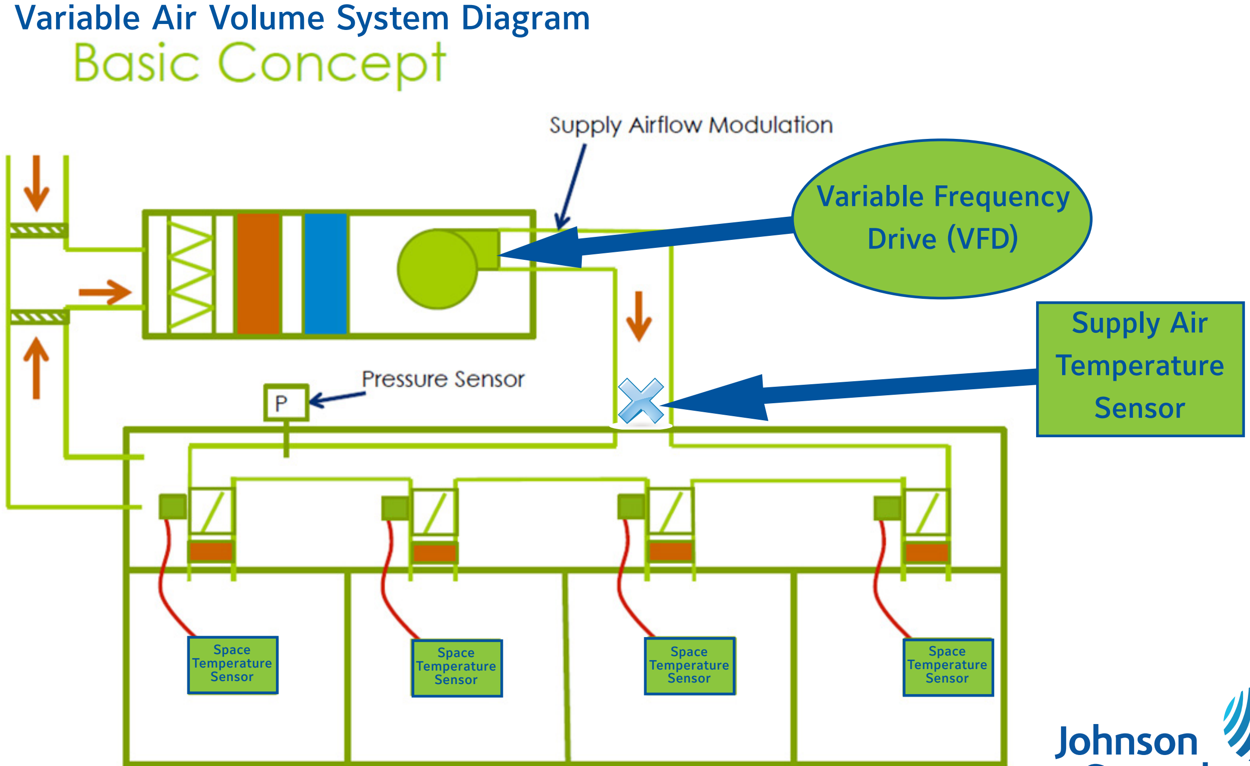
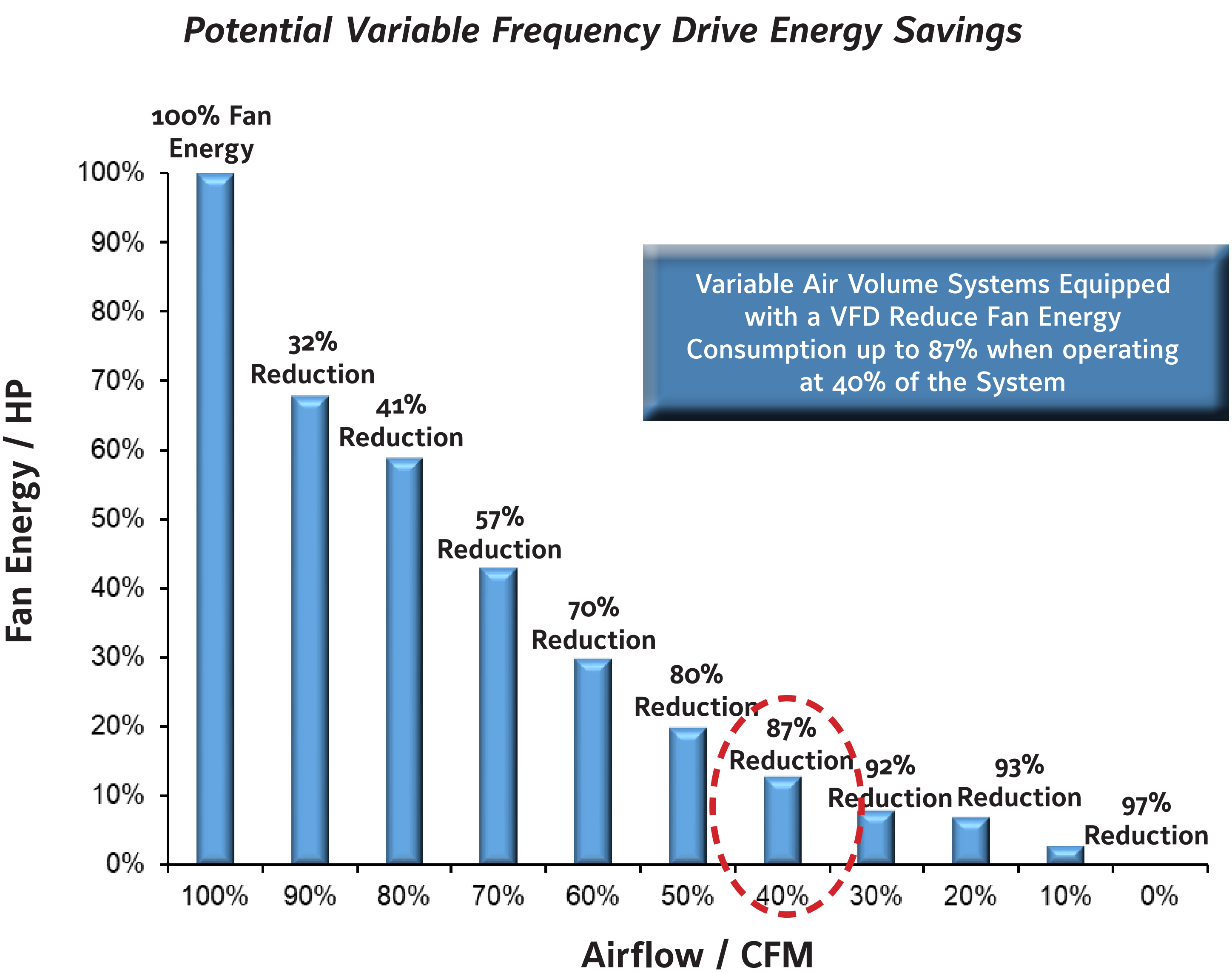


Figure 8. Variable Air Volume or IntelliSpeed w/VFD Energy Consumption

Utilizing a VFD to vary fan speed increases the motor efficiency when running below 100% of full load or less than 60hz. The table shown below provides potential energy/HP reduction at reduced VFD output frequency. The reduced frequency results in lower fan speed and increased motor efficiency.

For example a Ducted Systems product equipped with the IntelliSpeed option will typically run the first stage of cooling during off peak cooling season. Operating on the first stage of cooling will operate the VFD at approximately 67% of total air volume and that results in approximately a 64% energy usage reduction of the supply fan motor.

The motor energy savings are even greater when a VFD is applied to a VAV system. VAV systems will operate based on maintaining a constant SAT and duct pressure. During the majority of the off peak cooling season the conditioned zones will require little or no cooling resulting in supply fan motor energy savings of up to 80-90%.



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